

## **The New National Vision for Space Exploration**

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### **ABSTRACT**

From the Apollo landings on the Moon, to robotic surveys of the Sun and the planets, to the compelling images captured by advanced space telescopes, U.S. achievements in space have revolutionized humanity's view of the universe and have inspired Americans and people around the world. These achievements also have led to the development of technologies that have widespread applications to address problems on Earth. As the world enters the second century of powered flight, it is appropriate to articulate a new vision that will define and guide U.S. space exploration activities for the next several decades.

Today, humanity has the potential to seek answers to the most fundamental questions posed about the existence of life beyond Earth. Telescopes have found planets around other stars. Robotic probes have identified potential resources on the Moon, and

evidence of water – a key ingredient for life – has been found on Mars and the moons of Jupiter.

Direct human experience in space has fundamentally altered our perspective of humanity and our place in the universe. Humans have the ability to respond to the unexpected developments inherent in space travel and possess unique skills that enhance discoveries. Just as Mercury, Gemini, and Apollo challenged a generation of Americans, a renewed U.S. space exploration program with a significant human component can inspire us – and our youth – to greater achievements on Earth and in space.

The loss of Space Shuttles Challenger and Columbia and their crews are a stark reminder of the inherent risks of space flight and the severity of the challenges posed by space exploration. In preparation for future human exploration, we must advance our ability to live and work safely in space and, at the same time, develop the technologies to extend humanity's reach to the Moon, Mars, and beyond. The new technologies required for further space exploration also will improve the Nation's other space activities and may provide applications that could be used to address problems on Earth.

Like the explorers of the past and the pioneers of flight in the last century, we cannot today identify all that we will gain from space exploration; we are confident, nonetheless, that the eventual return will be great. Like their efforts, the success of future U.S. space exploration will unfold over generations.

The fundamental goal of this new national vision is to advance U.S. scientific, security, and economic interests through a robust space exploration program. In support of this goal, the United States will:

- Implement a sustained and affordable human and robotic program to explore the solar system and beyond;
- Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;
- Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and
- Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

## **INTRODUCTION**

The U.S. Vision for space exploration is bold and forward-thinking. It expands scientific discovery and the search for habitable environments and life by advancing human and robotic capabilities across multiple worlds. This plan provides the framework for

fulfilling the nation's future in space. The new national plan is responsive to recent science findings, the NASA Strategic Plan, the report of the Columbia Accident Investigation Board, and the new space exploration policy. It seeks to establish a sustainable and flexible approach to exploration by pursuing compelling questions, developing breakthrough technologies, leveraging space resources, and making smart decisions about ongoing programs. It will help drive critical national technologies in power, space propulsion, computing, nanotechnology, biotechnology, communications, networking, robotics, and materials. It will start exciting new programs now to inspire the next generation of explorers. The guiding principles for NASA's new era of exploration are shown in Table 1.

Our generation inherited great legacies from the exploratory voyages and discoveries of earlier centuries. Starting with an exploration roadmap (see Figure 1), this paper describes an approach for achieving great legacies that our century can leave to future generations.

INSERT TABLE 1

INSERT FIGURE 1



# Table 1

## NASA Guiding Principles for Exploration

### **Pursue Compelling Questions**

Exploration of the solar system and beyond will be guided by compelling questions of scientific and societal importance. NASA exploration programs will seek profound answers to questions about the origins of our solar system, whether life exists beyond Earth, and how we could live on other worlds.

### **Across Multiple Worlds**

NASA will make progress across a broad front of destinations, starting with a return to the Moon to enable future human exploration of Mars and other worlds. Consistent with recent discoveries, NASA will focus on possible habitable environments on Mars, the moons of Jupiter, and in other solar systems. Where advantageous, NASA will also make use of destinations like the Moon and near-Earth asteroids to test and demonstrate new exploration capabilities.

### **Employ Human and Robotic Capabilities**

NASA will send human and robotic explorers as partners, leveraging the capabilities of each where most useful. Robotic explorers will visit new worlds first, to obtain scientific data, assess risks to our astronauts, demonstrate breakthrough technologies, identify space resources, and send tantalizing imagery back to Earth. Human explorers will follow to conduct in-depth research, direct and upgrade advanced robotic explorers, prepare space resources, and demonstrate new exploration capabilities.

### **For Sustainable Exploration**

NASA will pursue breakthrough technologies, investigate lunar and other space resources, and align ongoing programs to develop sustainable, affordable, and flexible solar system exploration strategies.

### **Use the Moon as a Testing Ground For Mars and Beyond**

Under this new Vision, the first robotic missions will be sent to the Moon as early as 2008 and the first human missions as early as 2015 to test new approaches, systems and operations for sustainable human and robotic missions to Mars and beyond.

### **Starting Now**

NASA will pursue this Vision as our highest priority. Consistent with the FY 2005 Budget, NASA will immediately begin to realign programs and organization, demonstrate new technical capabilities, and undertake new robotic precursor missions to the Moon and Mars before the end of the decade.

## **SOLAR SYSTEM AND BEYOND EXPLORATION ROADMAP**

Following up on the highly successful Mars Exploration Rover (MER) Program in early 2004, NASA plans to send additional robotic probes to explore our solar system, including our Earth's Moon, the planet Mars, the moons of Jupiter and other outer planets, and will launch new space telescopes to search for planets beyond our solar system over the next three decades. These robotic explorers will pursue compelling scientific questions, demonstrate breakthrough technologies, identify space resources, and extend an advanced telepresence that will send stunning imagery back to Earth.

Starting at the Moon in 2008 and at Mars in 2011, NASA will launch dedicated robotic missions that will demonstrate new technologies and enhance our scientific knowledge of these destinations. These new technologies and discoveries will pave the way for more capable robotic missions and eventually human missions. The first human explorers will be sent to the Moon as early as 2015, but no later than 2020, as a stepping stone to demonstrate sustainable approaches to exploring Mars and other worlds.

To support these missions, a number of key building blocks are necessary. These include new capabilities in propulsion, power, communications, crew transport, and launch, as well as the refocusing of ongoing programs like Space Station research. Major achievements, including the completion of Space Station assembly, test flights of new

crew transport capabilities, and space technology demonstrations, are expected before the end of this decade.

The activities in each of the sections in this roadmap, Moon, Mars, Outer Moons, Extrasolar Plants, and Exploration Building Blocks, are described in the next sections of this paper.

## **LUNAR TESTBEDS AND MISSIONS**

During the late 1960s and early 1970s, the Apollo program demonstrated American technical strength in a race against the Soviet Union to land humans on the Moon. As summarized pictorially in Figures 2 & 3. Today, NASA's plans for a return to the Moon are not driven by Cold War competition, but by the need to test new exploration technologies and skills on the path to Mars and beyond. Additionally, during the 1990s, robotic missions identified potential evidence of water ice at the Moon's poles, a resource that could make exploration further into the solar system easier to conduct.

NASA will begin its lunar test bed program with a series of robotic missions. The first, an orbiter to confirm and map lunar resources in detail, will launch in 2008. A robotic landing will follow in 2009 to begin demonstrating capabilities for sustainable exploration of the solar system. Additional missions, potentially up to one a year, are planned to demonstrate new capabilities such as robotic networks, reusable planetary landing and launch systems, pre-positioned propellants, and resource extraction. Figure 4

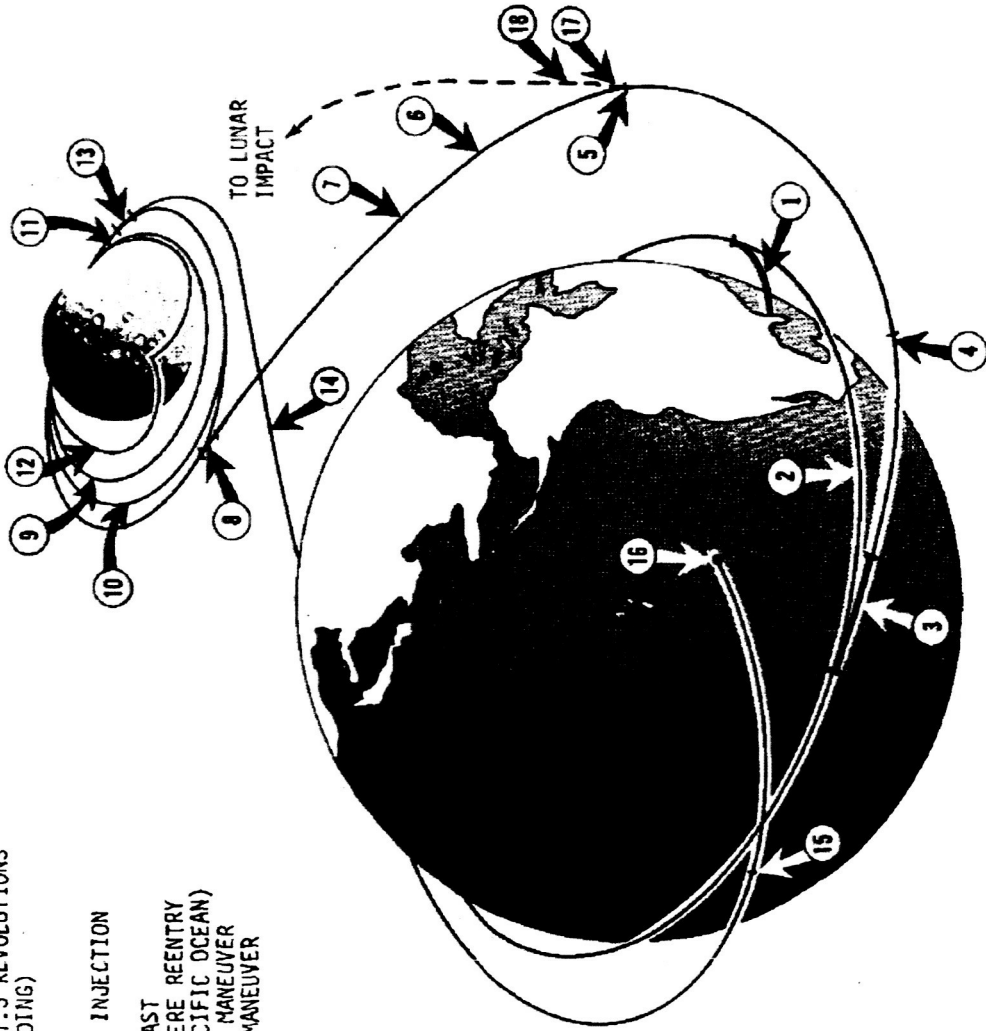




# Typical Apollo Transportation Segments

1. BOOST TO EARTH ORBIT
2. COAST IN EARTH ORBIT
3. S-IVB TRANS-LUNAR INJECTION BOOST
4. INITIATE TRANSPOSITION AND DOCKING MANEUVER
5. LV/SC FINAL SEPARATION
6. HYBRID MANEUVER (IF REQUIRED)
7. TRANS-LUNAR COAST
8. SM DEBOOST TO FIRST LUNAR ORBIT (LOI-1), 60 x 170 NAUTICAL MILES (NMI)
9. CSM MANEUVER TO LOI-2, 60 x 8 NMI (AFTER 2 REVOLUTIONS IN LOI-1)

10. CSM MANEUVER TO LOI-3, 60 x 60 NMI (1.5 REVOLUTIONS BEFORE LM LANDING)
11. LM DESCENT
12. LM ASCENT
13. SM TRANS-EARTH INJECTION BOOST
14. TRANS-EARTH COAST
15. EARTH ATMOSPHERE REENTRY
16. TOUCHDOWN (PACIFIC OCEAN)
17. S-IVB EVASIVE MANEUVER
18. S-IVB IMPACT MANEUVER

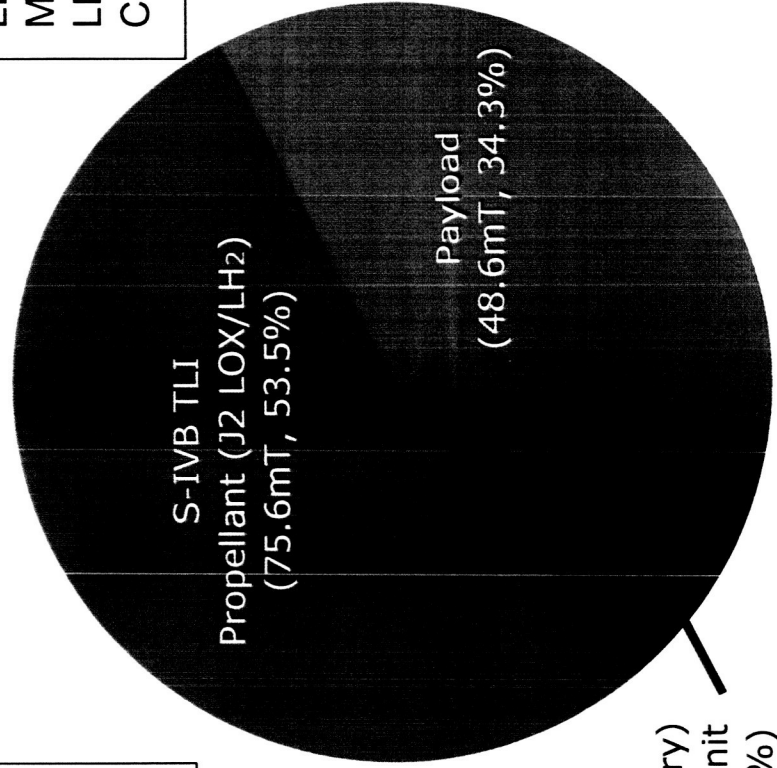




# Apollo Mass Inserted into Earth Parking Orbit (EPO)

141.5 mT Total Mass into 100nm Circular Parking Orbit

Lift-Off	6,521,700 lbs (1/1)
LEO	311,900 lbs (1/21)
MOI	107,100 lbs (1/61)
LEM	36,200 lbs (1/180)
CM	12,800 lbs (1/510)



## Payload:

Command Module	12,800lbs.
Service Module	54,100lbs.
Lunar Module	36,200lbs.
Spacecraft	
Lunar Module Adapter	4,000lbs.
	107,100lbs. (48.6mT)

Over Half the Mass Inserted into LEO was the TL Propellants!

compares the basic differences in these two approaches i.e., (Apollo vs. steady progressive exploration).

A human mission to the Moon will follow these robotic missions as early as 2015. The Moon will provide an operational environment where we can demonstrate human exploration capabilities within relatively safe reach of Earth. Human missions to the Moon will serve as precursors for human missions to Mars and other destinations, testing new sustainable exploration approaches, such as space resource utilization, and human-scale exploration systems, such as surface power, habitation and life support, and planetary mobility. The scope and types of human lunar missions and systems will be determined by their support to furthering science, developing and testing new approaches, and their applicability to supporting sustained human space exploration to Mars and other destinations.

The major focus of these lunar activities will be on demonstrating capabilities to conduct sustained research on Mars and increasingly deep and more advanced exploration of our solar system. Additionally, these robotic and human missions will pursue scientific investigations on the Moon, such as uncovering geological records of our early solar system.

## **MARS RESEARCH, TESTBEDS, AND MISSIONS**

As early as the 19<sup>th</sup> century, telescope observations led some astronomers to speculate that Mars might harbor life. Subsequent robotic missions to Mars during the 1960s and 1970s showed that the surface of Mars is currently inhospitable. However, more recent missions have transformed our understanding of Mars. New data indicates that liquid water likely flowed across the surface of Mars in the distant past and may still exist in large reservoirs deep underground. This raises the prospect that simple forms of life may have been developed early in Mars' history and may persist beneath the surface of Mars to this day.

NASA is aggressively pursuing the search for water and life on Mars using robotic explorers. The MER Spirit and Opportunity rovers that landed on Mars in January 2004 are the latest in a series of research missions planned to explore Mars through 2010. By the end of this decade, three rovers, a lander, and two orbiters will have visited the planet. NASA will augment this program and prepare for the next decade of Mars research missions by investing in key capabilities to enable advanced robotic missions, such as returning geological samples from Mars or drilling under the surface of Mars. This suite of technologies will enable NASA to rapidly respond to discoveries this decade and pursue the search for water and life at Mars wherever it may lead next decade.

Starting in 2011, NASA will also launch the first in a new series of human precursor missions to Mars. These robotic testbeds will demonstrate technologies – such as improved aerodynamic entry, Mars orbital rendezvous and docking, precision landing, resource extraction and utilization, and optical communications—that can greatly



# Call for a New Approach

## Apollo "One Giant Leap" Approach

- Cold War competition set goals, National security justified investment
- Singular focus of Moon
- Humans in space an end unto itself
- Robotic exploration secondary to crewed missions
- Rigid timeframe for completion with unlimited resources
- Inspirational outreach and education secondary to programs



05/13/04

## "SAFE" Approach

- SAFE: must demonstrate safety for the public, NASA workforce, and high-value equipment
- Sustainability: ability to maintain for the long-term; discoveries, inspiration and educational outreach along the way
- Affordability: must be within budget; right mix of humans and robots
- Flexibility: ability to change in responses to changes; changes in technologies and priorities
- Evolvability: consistent with NASA's incremental "Stepping Stones" approach; Moon, Mars, and beyond



Chart 14

enhance future robotic capabilities and are key to enabling future human Mars missions. These missions will also obtain critical data for future human missions on chemical hazards, resource locations, and research sites (See Figure 5). They may prepare resources and sites in anticipation of human landings.

The first human mission beyond the Moon will be determined on the basis of available resources, accumulated experience, and technology readiness. Potential candidates that might be considered include circumnavigating Mars, visiting a near-Earth asteroid, or erecting or upgrading a deep space telescope. Such missions could test the human-scale power, propulsion, and other transit systems necessary to take trips to Mars before taking on the additional risk of a landing on Mars.

The timing of the first human research missions to Mars will depend on discoveries from robotic explorers, the development of techniques to mitigate Mars hazards, advances in capabilities for sustainable exploration, and available resources.

## **ESTRASOLAR PLANET RESEARCH AND OBSERVATORIES**

Our solar system is composed of nine planets, including Earth, that circle a central star, the Sun. Astronomers and philosophers have speculated for millennia about whether other stars harbor worlds like Earth and whether these worlds are inhabited. However, it is only in the last decade that telescopes have become powerful enough to detect whether planets of any type circle other stars. In 1995, astronomers discovered the first solar

system besides our own. Since then, astronomers have found over 100 planets orbiting other stars—and the number continues to climb with new discoveries.

All of the extrasolar planets discovered to date are either very large planets or planets that circle very close to their parent stars. Some extrasolar planets are many times larger than the largest planet in our solar system, Jupiter, and orbit even closer to their parent star than the closest planet to our Sun, Mercury. Because of the obscuring effects of the Earth's atmosphere, the detection and characterization of small planets with normal orbits like Earth is extremely challenging using ground-based telescopes.

NASA's Astronomical Search for Origins program will use a variety of techniques this decade to greatly expand the number and variety of known extrasolar planets. New space telescopes like the Spitzer and James Webb Space Telescopes, the Kepler mission, and the Space Interferometry mission, will search newly formed planets circling young stars, take planetary surveys of thousands of faraway stars, and detect planets only a few times larger than Earth around very nearby stars.

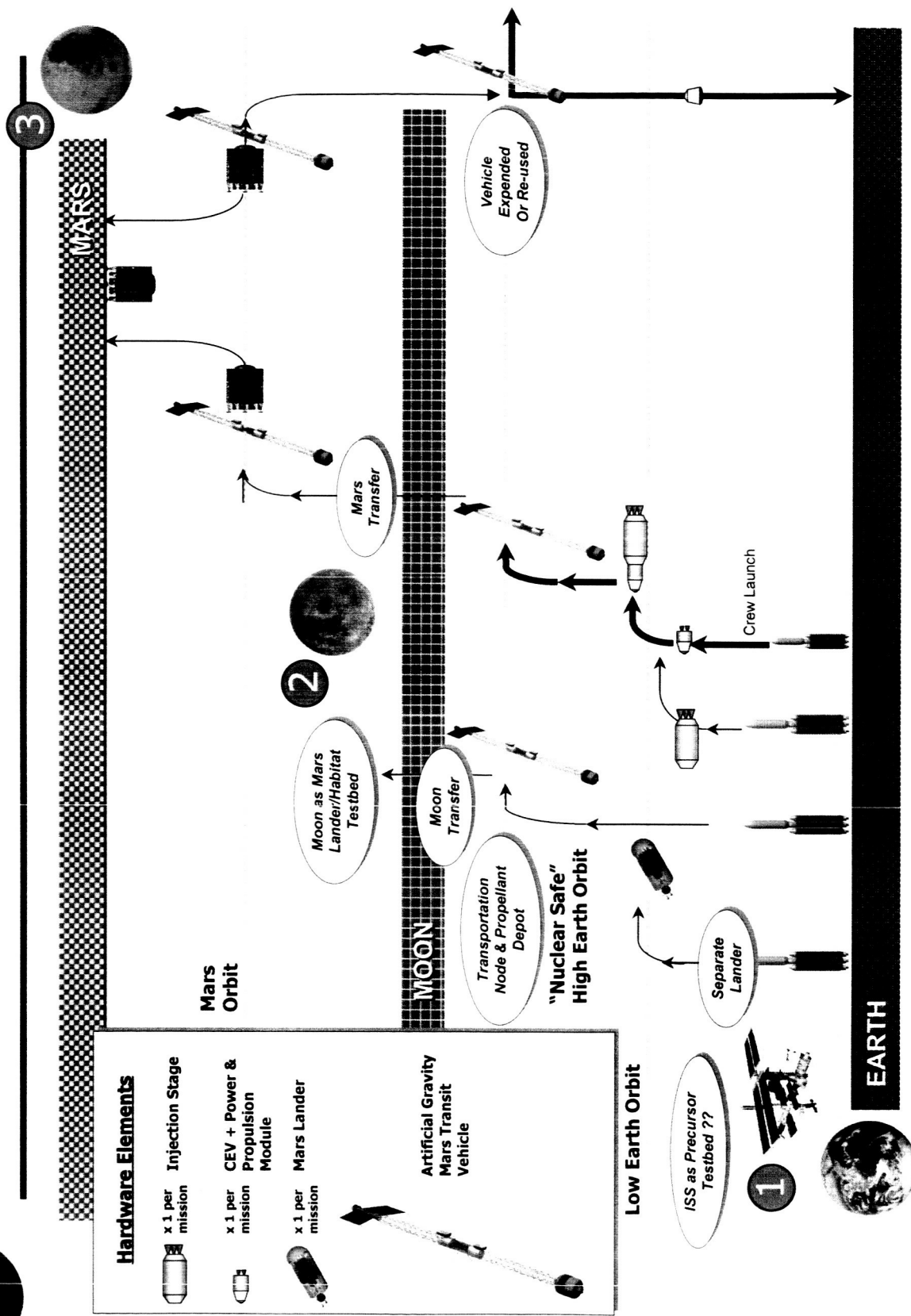
### **Exploration Building Blocks**

To conduct an effective and exciting program of exploration and discovery, we must overcome the limitations of space, time and energy, as well as various space hazards.

Over the next two decades, NASA plans to develop a number of new capabilities that are critical to enabling the human and robotic missions described in this document. Figure illustrates one notional approach for the future solar system exploration architecture.



# Notional Exploration Architecture



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Chart 16

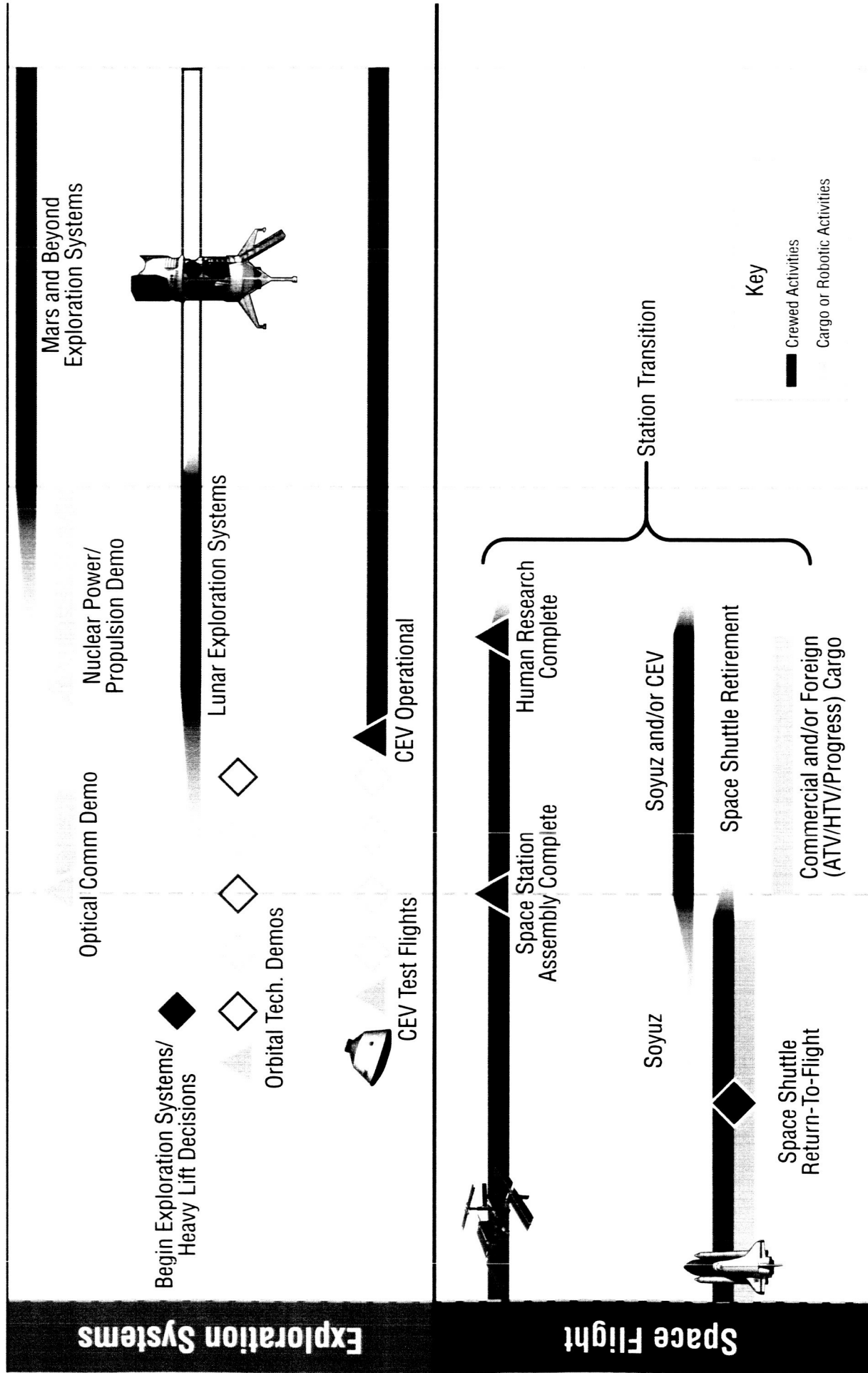


For human explorers to undertake lengthy research trips on other worlds, they will have to maintain their health in environments that possess higher radiation and lower gravity than Earth and that are far from supplies and medical expertise. Research aboard the International Space station and at various laboratories on Earth is critical to understanding the effects of space environments on the human body, developing techniques for mitigating these hazards, minimizing the logistical burden of supporting humans far from Earth, and addressing remote medical emergencies. NASA plans to complete assembly of the Space Station, including international partner elements, by the end of the decade. NASA will also augment its bioastronautics research program with the goal that Space Station research necessary to support human explorers on other worlds will be complete by 2016.

The Space Shuttle will be critical to completing assembly of the Space Station. With Space Station assembly complete at the end of this decade, NASA will retire the Space Shuttle and put crew and cargo on different launches, a safer approach to crew transport.

NASA will initiate Project Constellation to develop a new Crew Exploration Vehicle for future crew transport. This vehicle will be developed in stages, with the first automated test flight in 2008, more advanced test flights soon thereafter, and a fully operational capability no later than 2014. The design of the Crew Exploration Vehicle will be driven by the needs of the future human exploration missions described in this document. The Crew Exploration Vehicle might also supplement international partner crew transport systems to the Space Station.

# Exploration Building Blocks



2000

2010

2020

For cargo transport to the Space Station after 2010, NASA will rely on existing or new commercial cargo transport systems, as well as international partner cargo transport systems. NASA does not plan to develop new launch vehicle capabilities except where critical NASA needs-such as heavy lift-are not met by commercial or military systems. Depending on future human mission designs, NASA could decide to develop or acquire a heavy lift vehicle later this decade. Such a vehicle could be derived from elements of the Space Shuttle, existing commercial launch vehicles, or new designs. In-space operations and on-orbit servicing may drive the design of the space transportation architecture. One advanced technology that may play an important role is autonomous rendezvous and docking (AR&D) and, other in-space operations. In-space propellant management (cryogenic propellant storage, transfer, gauging, etc.), and In-Situ Resource Utilization (ISRU) may also be critical and key technology areas to enable future exploration missions (See Figure ).

In the days of the Apollo program, human exploration systems employed expendable, single-use vehicles requiring large ground crews and careful monitoring. For future, sustainable exploration programs, NASA requires cost-effective vehicles that may be reused, have systems that could be applied to more than one destination, and are highly reliable and need only small ground crews. NASA plans to invest in a number of new approaches to exploration, such as robotic networks, modular systems, pre-positioned propellants, advanced power and propulsion, and in-space assembly, that could enable these kinds of vehicles. These technologies will be demonstrated on the ground, at the

Space Station and other locations in Earth orbit, and on the Moon starting this decade and into the next. Other break-through technologies, such as nuclear power and propulsion, optical communications, and potential use of space resources, will be demonstrated as part of robotic exploration missions. The challenges of designing these systems will accelerate the development of fundamental technologies that are critical not only to NASA, but to the Nation's economic and national security.

### **NASA Transformation**

To successfully execute national exploration vision as directed by the President, NASA will refocus its organization, create new offices where necessary, realign ongoing programs and personnel, experiment with new ways of doing business, and tap the great innovative and creative talents of our Nation.

Prior to this plan, six Enterprises comprised NASA's organization-Space Science, Earth Science, Biological and Physical research, Aerospace Technology, Education, and Space flight. To develop the exploration building blocks described in this document, NASA has created a new Exploration Systems Enterprise. Exploration Systems will be initially responsible for developing the solar system exploration vehicles and technologies described in this plan, including the Crew Exploration Vehicle, nuclear power and propulsion systems, and necessary supporting technologies. Relevant elements of the Aerospace Technology, Space Science, and Space Flight enterprises were transferred to

the Exploration Systems Enterprise. The Aerospace Technology Enterprise was renamed the Aeronautics Enterprise.

In the past, NASA's human space flight programs and robotic exploration programs have largely operated independently of each other. As human explorers prepare to join their robotic counterparts, closer coordination and integration will be necessary. The Exploration Systems Enterprise will work closely with the Space Science and other Enterprises to use the Moon and earth orbit asset as testbeds for solar system exploration vehicles and technologies.

As we move outward into the solar system, NASA will rely more heavily on private sector space capabilities to support activities in Earth orbit and future exploration activities. In particular, NASA will seek to use existing or new commercial launch vehicles for cargo transport to the Space Station, and potentially to the Moon and other destinations.

Building on its long history and extensive and close ties with the space and research agencies of other nations, NASA will also actively seek international partners and work with the space agencies of these partners in executing future exploration activities.

Many of the technical challenges that NASA will face in the coming years will require innovative solutions. In addition to tapping creative thinking within the NASA

organizations, NASA will need to leverage the ideas and expertise resident in the Nation's universities and industry. One way that NASA plans to do this is through a series of Centennial Challenges. As in the barnstorming days of early aviation, NASA plans to establish prizes for specific accomplishments that advance solar system exploration and other NASA goals.

### **Summary and Conclusions**

Just as Meriwether Lewis and William Clark could not have predicted the settlement of the American West within a hundred years of the start of their famous 19<sup>th</sup> century expedition, the total benefits of a single exploratory undertaking or discovery cannot be predicted in advance. Because the very purpose of exploratory voyages and research is to understand the unknown, exact benefits defy calculation. Nonetheless, we can define important categories of benefits to the Nation and society.

Preparing for exploration and research accelerates the development of technologies that are important to the economy and national security. The space missions under consideration require advanced systems and capabilities that will accelerate the development of many critical technologies, including power, advanced propulsion, computing, nanotechnology, biotechnology, communications, networking, robotics, and materials. These technologies underpin and advance the U.S. economy and help ensure

national security. NASA plans to work with other government agencies and the private sector to develop space systems that can address national and commercial needs.

Space exploration holds a special place in the human imagination. Youth are especially drawn to Mars rovers, astronauts, and telescopes. If engaged effectively and creatively, space inspires children to seek careers in math, science, and engineering. Careers that are critical to our future national economic competitiveness.

The accomplishments of U.S. space explorers are also a particularly potent symbol of American democracy, a reminder of what the human spirit can achieve in a free society. However, space exploration also encourages international cooperation, where spacecraft and explorers come to represent our world as well as our Nation.

The Nation's vision for solar system exploration must be affordable in both the short-term and long-term. In particular, an integrated space transportation architecture (ISTA) must be developed that recognizes the need for development of high-leverage, but highly economical and effective technologies, because as was the case for Apollo, Space Shuttle, Sky Lab, and ISS, the transportation elements of any new exploration program will require the largest investments. The ISTA must be based upon well integrated (all NASA needs and all space transportation regimes) and well defined propulsion capabilities directly keyed to all the space transportation element requirements as discussed in this paper.

When the unknown becomes known, it catalyzes change, stimulating human thought, creativity and imagination. The scientific questions that this plan pursues have the potential to revolutionize whole fields of research. For example, scientists are still working to understand how similarly sized planets, such as Mars and Earth, could have developed so differently and what that could mean for our planet. If life is found beyond Earth, biological processes on other worlds may be very different from those evolved on our world. Outside the sciences, the very knowledge that life exists elsewhere in the universe may hold revelations for fields in the humanities.

The U.S. has a great history of space successes, and the new Vision for Space Exploration provides a clear direction for building on this past. Finally, to continue this legacy of space successes, the critical importance of continuing basic Space Technology research simply cannot be overstated. It is so vitally important, not just for enabling near-term and future U.S. space missions; but it is also crucial to enable the next generation of space explorers and to revitalize young people's interests in pursuing science, technology, and engineering careers for all areas of future U.S. technology development.